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UNITED STATES
DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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PUMPING OPERATIONS IN THE CRIPPLE CREEK DISTRICT, COLO.

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PUMPING OPERATIONS IN THE CRIPPLE CREEK DISTRICT, COLO.[1]

By Jos. R. Guiteras[2]

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2/ Mining engineer, Mining Division, Metal Mining Methods Section, Bureau of Mines.

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INTRODUCTION

This paper describes the pumping operations at the Ajax, Cresson, and Vindicator mines in the Cripple Creek mining district of Colorado during the summer of 1936. At that time the three mines were pumping 6,500 gallons of water per minute into the Roosevelt drainage tunnel. Cripple Creek is the most important gold district in the State; it has yielded gold valued at over $365,000,000. The mines engaged in pumping are among the largest producing properties in the district.

ACKNOWLEDGMENTS

The author wishes to acknowledge the friendly cooperation of mine officials at the properties visited. At the Ajax mine information was courteously given by Clayton Kissel, mine superintendent, and his staff; R. N. Roby contributed the drawings. For information on the Cresson mine, thanks are expressed to Al H. Bebee, mine superintendent, and his staff, especially to Guy Rorabaugh, master mechanic, and to engineer Carlton. At the Vindicator mine, J. S. Anderson, mine superintendent, and Robert Welch, master mechanic, assisted; the latter furnished most of the information about that mine. Acknowledgment is also made of the cooperation of M. H. Salsbury, engineer at the Portland mine, who supplied technical data on the Roosevelt drainage tunnel.

CRIPPLE CREEK DISTRICT

Gold was first discovered by Bob Womack in 1891 in what is now the Cripple Creek mining district. The district comprises an area of some 12 square miles lying about 9 miles southwest of Pikes Peak; altitudes range from 9,000 to almost 11,000 feet above sea level. The district can be reached easily from Colorado Springs over the State highway via Divide or over the new Corley toll road; the distance by either route is about 45 miles. The winters are not as severe as the altitude would suggest, and mining is carried on the year round; the summer climate is ideal. At the northern end of the district is the town of Cripple Creek, county seat of Teller County, with a population of about 2,500; at the southern end is the town of Victor, a little smaller. A paved highway about 6 miles long connects the two.

Geology

The geology of the Cripple Creek mining district has been described by Lindgren and Ransome[3] and more recently by Loughlin[4] and by Loughlin and

3/ Lindgren, Waldemar, and Ransome, F. L., Geology and Gold Deposits of the Cripple Creek District, Colo.: Geol. Survey Prof. Paper 54, 1906, 516 pp.

4/ Loughlin, G. F., Ore At Deep Levels in the Cripple Creek District, Colo.: Am. Inst. Min. Eng. Trans., vol. 75, 1927, pp. 42-73.

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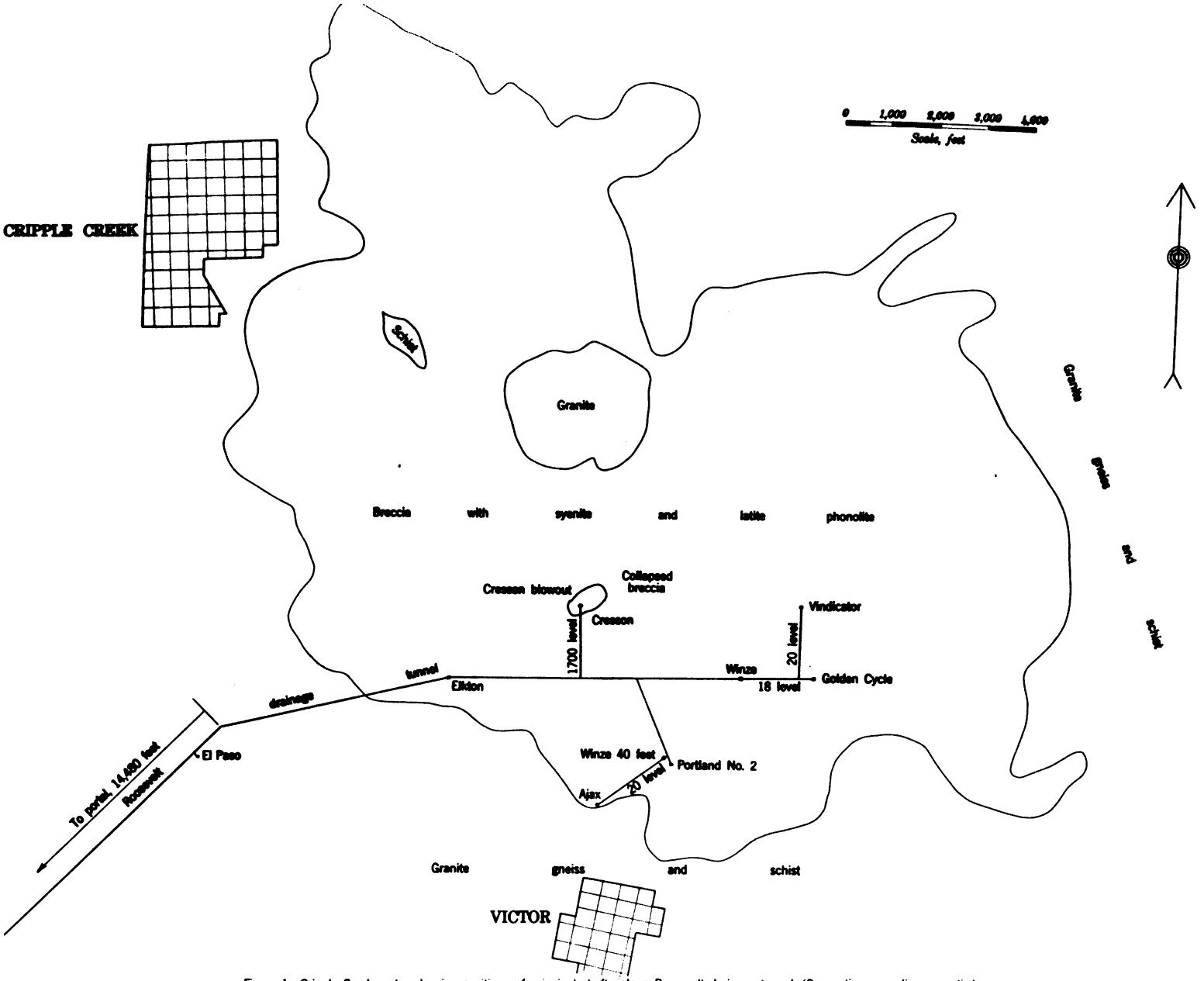

Figure 1.—Cripple Creek crater showing positions of principal shafts along Roosevelt drainage tunnel. (Connections are diagrammatic.)

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Koschmann.5/ Impetus to geologic study of the district was given recently by the problem of mine drainage with deeper mining, especially as it affected the justification for driving another and deeper drainage tunnel in the district. From these studies it appears that explosive eruptions in fissured granite produced many local craters, which coalesced toward the surface to form the Cripple Creek crater. (See fig. 1.) The rocks within the composite crater are mostly breccia and phonolite. Dikes cut the rocks within the crater and also the surrounding granite. Ore-bearing solutions rose through the subcraters and connecting networks of fissures. Similarly, the ground water now within the composite crater occupies the same fissure systems and subcraters; it becomes segregated into separate bodies with a lowering of the general water level. The surrounding granite is relatively impervious.

Gold Production

Although one of the smallest in area of Colorado's mining districts, the Cripple Creek district has yielded over half of the gold produced in the State. The peak production for the district was reached in 1900, when $18,149,645 in gold was produced. The following statistics6/ indicate the importance of the Cripple Creek district in Colorado mining during 1935.

Gold produced in Colorado and Cripple Creek, 1935.

	Cripple Creek district	State of Colorado
Number of lode mines producing gold in 1935	122	870
Number of placer mines producing gold in 1935	8	842
Short tons of ore from lode mines sold or treated for gold in 1935	460,448	1,770,984
Ounces of gold produced at lode mines in 1935	124,287.66	329,917.8
Ounces of gold produced at placer mines in 1935	36.34	19,363.0
Value of gold produced at lode and placer mines in 1935	$4,351,340	$12,224,828

Preliminary figures for 1936 show an increase of about 4.4 percent in the gold production of Colorado and an increase of about 13.1 percent in the production of the Cripple Creek district. Gold ore mined in the district during 1936 represents a smaller number of operations than in 1935; most of them are conducted by lessees. From 1,500 to 2,000 men are employed in the mines.

5/ Loughlin, G. F., and Koschmann, A. H., Geology and Ore Deposits of the Cripple Creek District, Colo.: Colo. Scientific Soc. Proc., Vol. 13, No. 6, pp. 217-435, 1935.

6/ Henderson, Chas. W., and Martin, A. J., Gold, Silver, Copper, Lead, and Zinc in Colorado: Minerals Yearbook 1936, U. S. Bureau of Mines, 1936, pp. 243-279.

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UNWATERING OPERATIONS

Encouraging gold values encountered below the natural ground water level in the early history of the camp led to pumping. With deeper mining, tunnels were driven to drain the district or parts of it. The principal tunnels driven for mine drainage in the district are:[7]

1896 - Ophelia tunnel at west base of Gold Hill.
1898 - Standard tunnel from west slope of Beacon Hill.
1903 - Tunnel to penetrate El Paso mine.
1907-1918 - Roosevelt tunnel.

In his interesting chronologic history of the driving of the Roosevelt drainage tunnel, Henderson[8] states that the tunnel was started on May 11, 1907, to gain 740 feet of drainage, and that it was completed to its present length of 24,255 feet in 1918. The tunnel is 6 feet high and 10 feet wide and cost about $28 per foot; it is untimbered.

Mines in the southern part of the district continue to find ore below the water level. Encouraged by the present price ($35 an ounce) of gold and by the gratifying results of deep development at some of the properties, many mining companies in the district are undertaking an increasing amount of sinking and unwatering. In August 1936, pumping from deep levels was being done at the Ajax, Cresson, and Vindicator mines. The water pumped from the mines is delivered to the Roosevelt drainage tunnel. Figure 2 shows a vertical section of the deep shafts in the district that are connected with the tunnel.

The water runs "open" in the drainage tunnel; there is no flume except for a few feet at the measuring weir near the portal. The weir is of the rectangular type with end contractions; figure 3 shows the general arrangements.

Measurements and calculations are made weekly. The quantity of water flowing over the weir is calculated from the formula:[9]

$$Q = h^{3/2}ca, \text{ where}$$

Q = quantity of water in second-feet.
h = head of water over crest of weir, in feet. This is determined by stretching a string horizontally from a stick to a rule held vertically on the crest of the weir. A reference nail on the stick is 11-1/2 inches above the crest of the weir; the usual (August 1936) water level is a little below the nail.

7/ Application for proposed deep drainage-tunnel project for the Cripple Creek mining district by the Mine Owners Association of Cripple Creek, Colo., 1935.

8/ Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, 1926, 263 pp.

9/ Not strictly applicable to a contracted weir, but more convenient to use. The error is probably not greater than the error in the measurement of "h."

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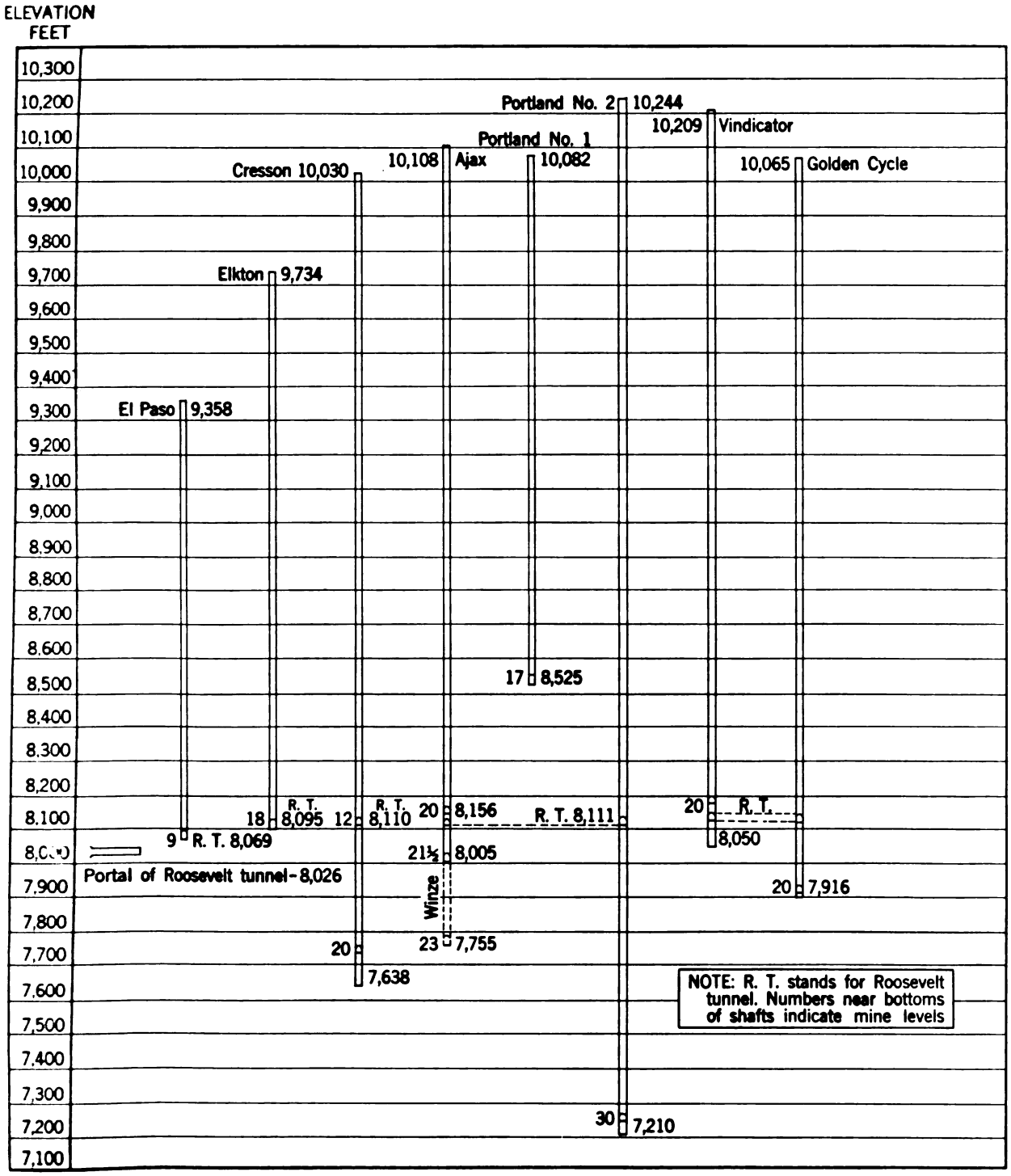

Figure 2.—Shafts of deep mines of Cripple Creek district connected with Roosevelt tunnel (U. S. G. S. datum plane).

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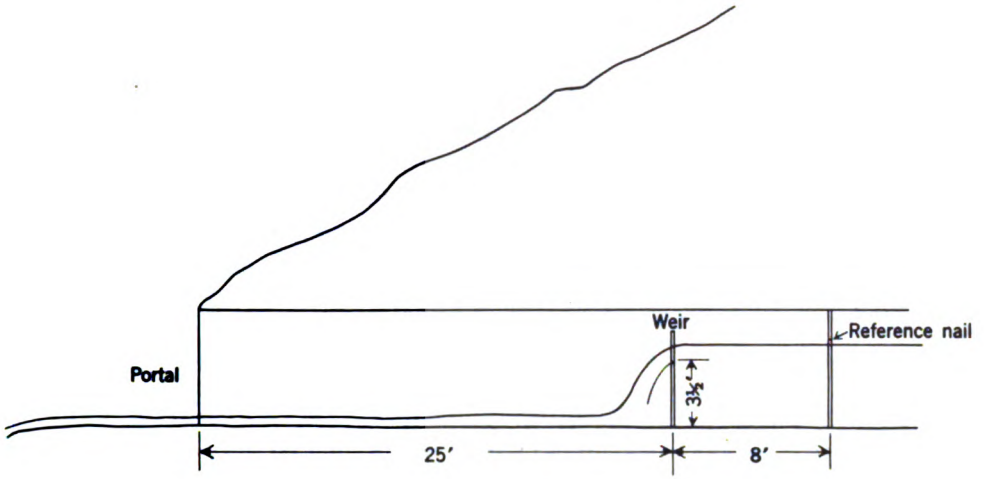

Figure 3.—Weir at portal of Roosevelt drainage tunnel.

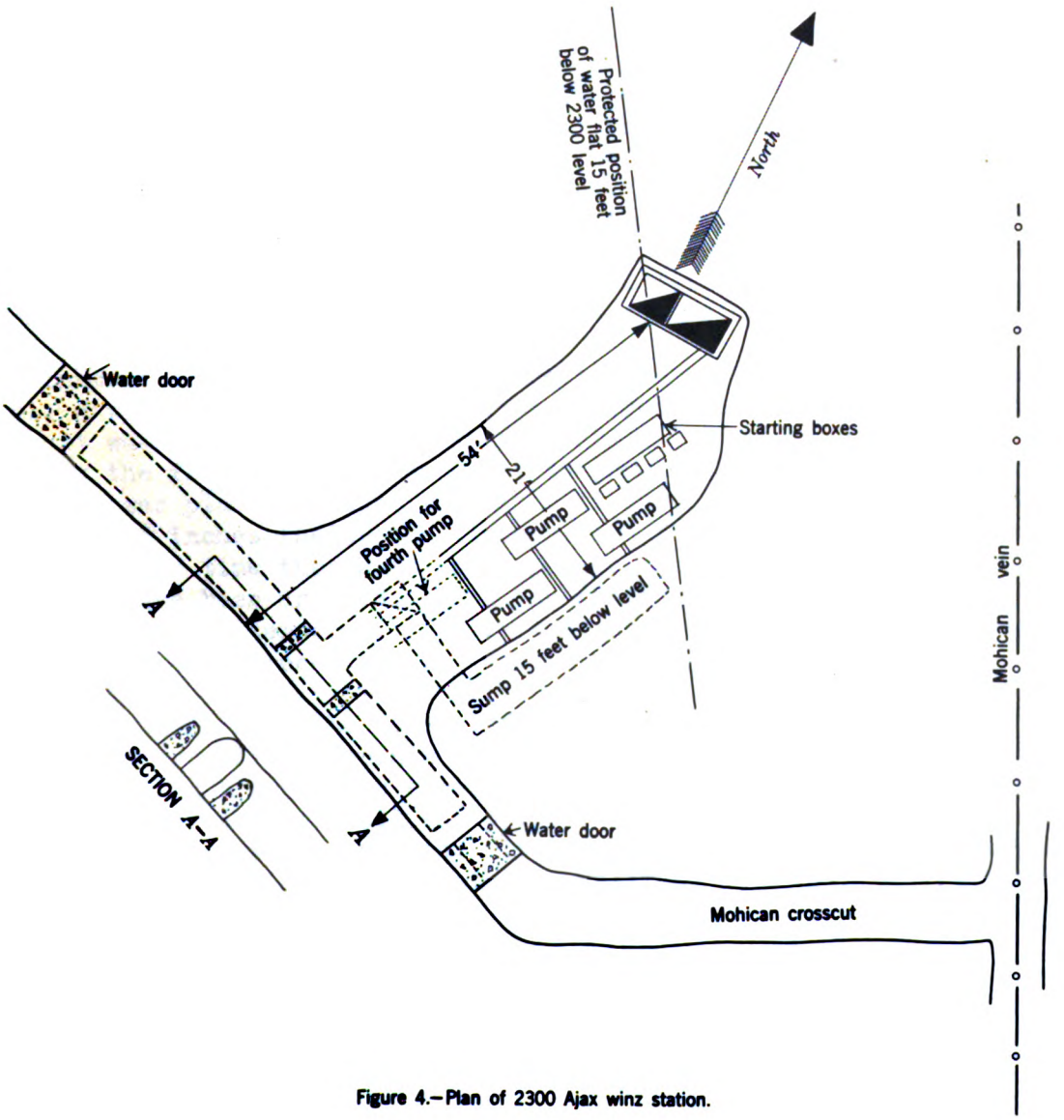

Figure 4.—Plan of 2300 Ajax winz station.

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c = constant, 3.3 used in this case.
a = width of weir in feet, 3.0 in this case.

The flow of water over the weir always measures less than the combined amounts of water pumped into the tunnel at the Ajax, Cresson, and Vindicator mines. In the summer of 1936 the discrepancy was about 2,000 gallons per minute. This condition would indicate either considerable error in one or more of the water measurements or a seepage of water from the drainage tunnel into the rocks.

Three power lines pass through the district - one from Canon City and two from Pueblo; service is therefore very dependable.

Ajax Mine, Golden Cycle Corporation

The Ajax mine is in the southern part of the Cripple Creek crater, as shown in figure 1. The main shaft is about a quarter of a mile north of Victor; the elevation of the shaft collar is 10,108.17 feet. The mine was shipping about 100 tons of gold ore a day in August 1936 and there were 114 men on the payroll. The ore was mined in shrinkage stopes averaging from 5 to 6 feet in width. About 85 percent of the ore hoisted was shipped; it averaged an ounce of gold to the ton and obviously justified the pumping cost of about $100 a day. The Golden Cycle Corporation of Colorado Springs bought the property from the International Mining Corporation of New York on August 23, 1935. At that time the bottom of the mine was the bottom of the main shaft at the 2,150 level. The new owners believed that ore bodies would be encountered between the 2,150 and 2,300 level, and subsequently developed and stoped ore at this horizon.

Instead of deepening the main shaft from the 2,150 level to the 2,300 level, a winze was sunk a short distance from the shaft. This was done because it was foreseen that the shaft would cut a water fissure and that probably the flow would be too great to permit the sinking to continue. The winze was placed so that the water fissure was avoided. It is 4 feet by 10 feet 8 inches inside the timbers; 104 feet of it was sunk in one month. By the time the shaft is deepened, much of the water from the fissure will have been drained. When the shaft reaches the fissure, sinking will be suspended temporarily while the water is sealed off with cement; sinking will then proceed.

At the Ajax mine the water inflow does not seem to be affected by seasons; apparently it depends upon the water pockets cut by underground workings. When a pocket is encountered, as by a drill hole, it is not penetrated by workings until the pumps have the flow well under control. The water is very slightly acid. It is clear except for fine rock particles picked up in fault channels. Water is regarded as a sign of fractured rocks that may carry ore.

About 1,500 gallons of water per minute had been pumped from the 2,150 station previous to sinking the winze to the 2,300 level. When the winze was sunk and the 2,300 station cut, 500 gallons per minute were pumped by

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auxiliary sinking pumps. The station was cut on the 2,300 level in January 1936, and the present pumping equipment (see p. 7), with the exception of the Lecourtenay pump, was installed at that time.

Figure 4 is a plan of the 2,300 winze station; it shows the sump arrangement and the position of the pumps and of the water doors in the crosscuts. Figure 5 is a vertical section through the station.

After the pumps were installed, the Mohican crosscut on the 2,300 level was driven. Water doors were constructed at the points shown in figure 4. The doors are made of 3/4-inch steel sheets reinforced by four 90-pound rails. Knee braces of 90-pound rails extend from the center of the door to hitches in the concrete foundation. Details of the construction are shown in figure 6. A similar water door was put on the 2,200 level during April and May 1936.

Water was encountered as the crosscut advanced and it became necessary to use the two Goulds pumps to handle the flow, which was about 1,500 gallons per minute. With the driving of the Newmarket crosscut, 2,000 gallons per minute were added to the flow. All four pumps were then required.

The winze development costs in 1936 are shown in the following tabulations:

Cost of excavating pump sump and widening station on 2,300-foot level. (Work done in January 1936)

Labor	$4,111.54
Compensation insurance	217.09
Stores	1,023.36
Hoisting	571.12
Air	851.56
Steel sharpening	163.02
New steel	196.42
Surface loading and tramming	66.64
	7,200.75

The station required the removal of 360 cubic yards of rock and the sump 150 cubic yards, making a total excavation of 510 cubic yards.

Cost of water doors (two) installed on 2,300 level, work done in January and February 1936

Labor	$ 695.45
Compensation insurance	36.72
Stores	518.65
	1,250.82
Total cost	8,451.57

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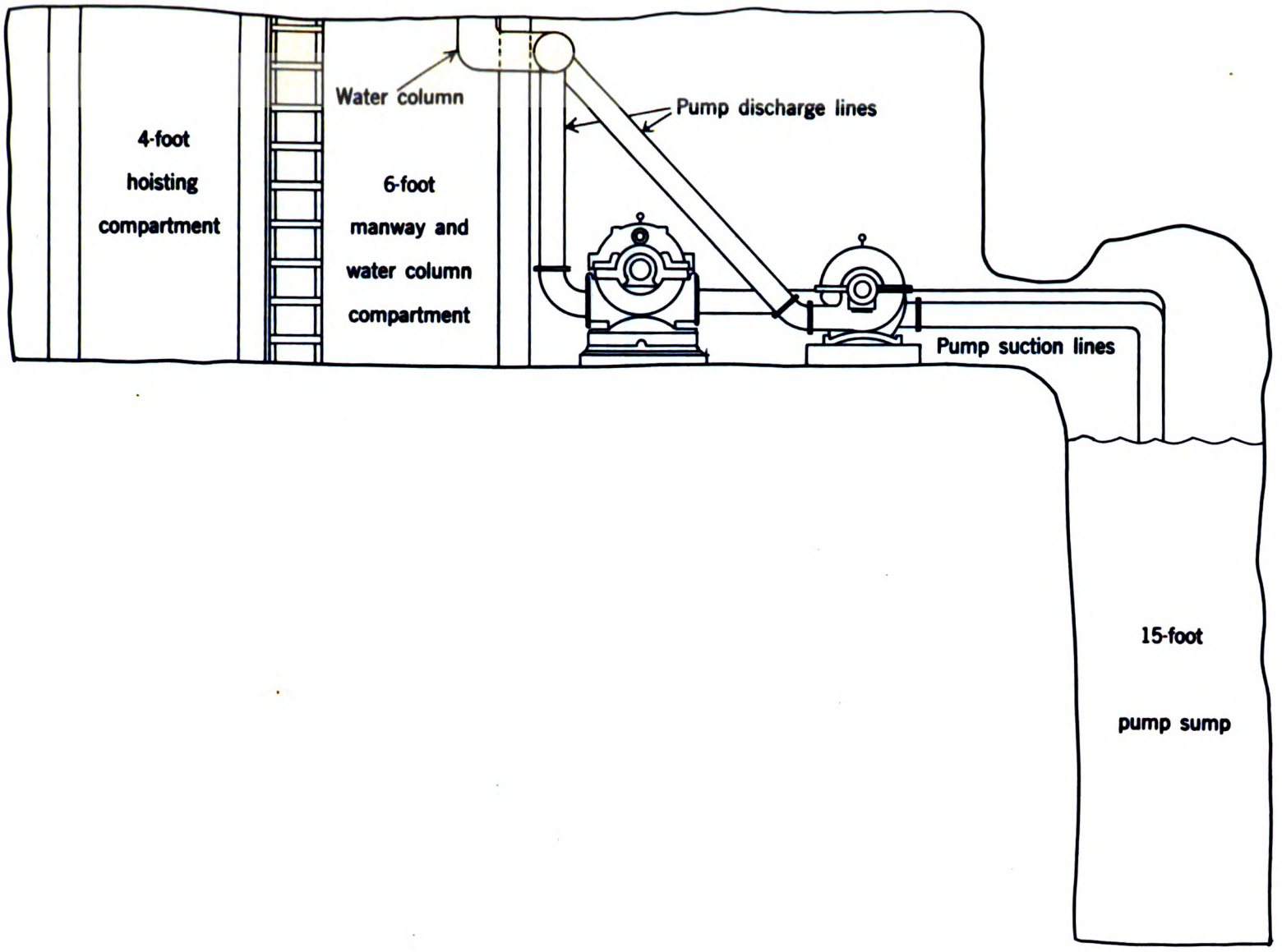

Figure 5.—Section through 2300 Ajax pump station.

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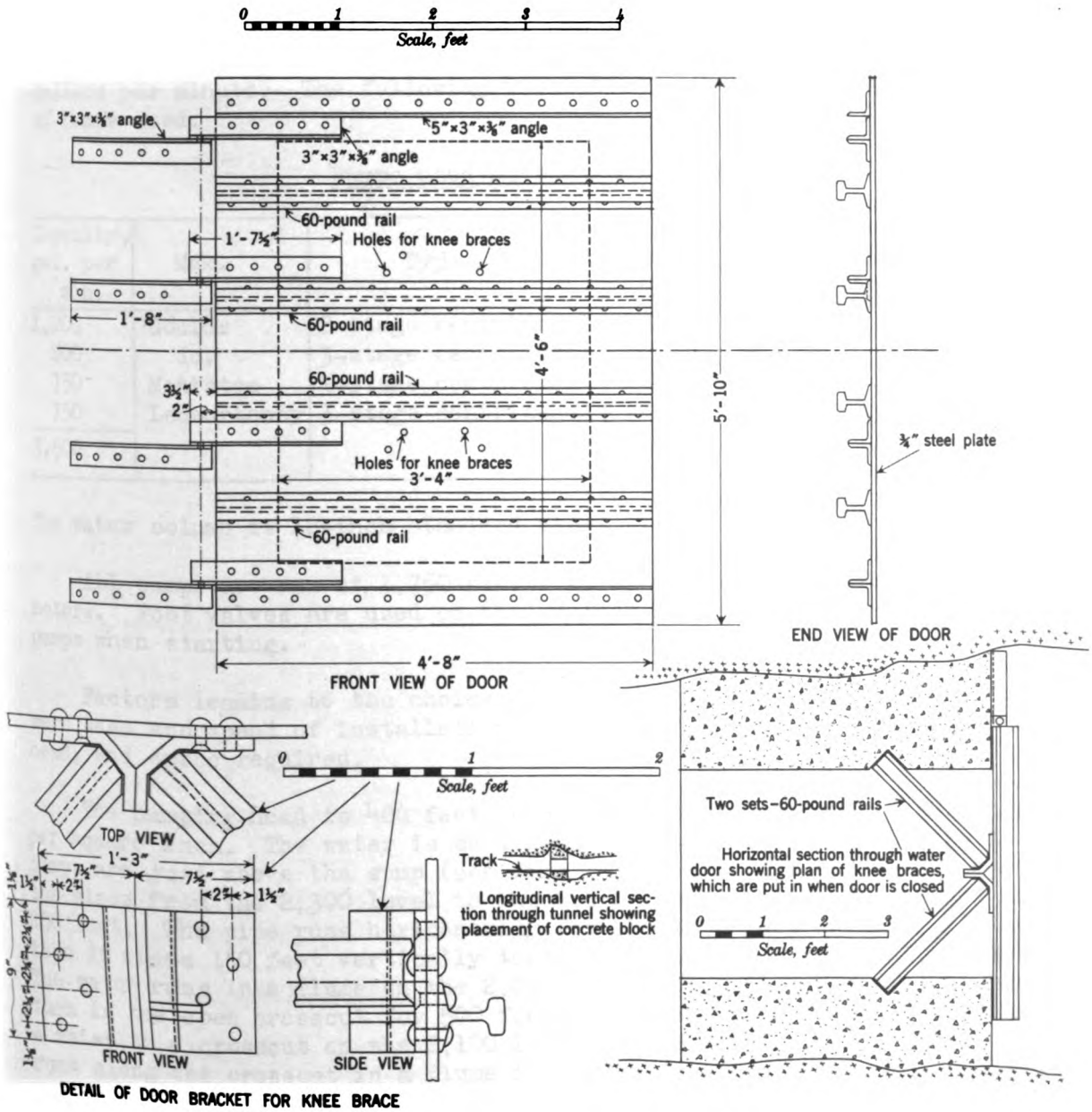

Figure 6.—Ajax water doors, 2,300-foot level.

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The foundations for the two water doors on the 2,300 level were constructed of a 1:2:3 concrete mixture. They required:

Cement	175 sacks
Sand	50,700 pounds
Gravel and rock..	67,600 pounds

In August 1936 the Ajax mine was pumping about 3,000 gallons per minute, using four centrifugal pumps whose combined capacity was 3,500 gallons per minute. The following tabulation shows the kinds and sizes of pumps used:

Pumps used at the Ajax mine

Capacity, gal. per min.	Make	Type	Hp. of motor	Suction pipe, inches	Discharge pipe, inches	Cost of pump only
1,200	Goulds	2-stage centrifugal	200	8	8	$ 685.66
800	do.	3-stage centrifugal	125	6	6	557.67
750	Manistee	3-stage centrifugal	125	6	6	500.00
750	Lecourtenay	3-stage centrifugal	125	6	5	(used)
3,500			575			1,743.33

The water column is 12-inch standard steel pipe.

All pumps are run at 1,750 r.p.m. by 2,300-volt, 3-phase, 30-cycle motors. Foot valves are used on the suction lines to assist in priming the pumps when starting.

Factors leading to the choice of centrifugal pumps for the station were ease and speed of installation, first cost, quantity of water, pumping head, and space required.

The pumping head is 400 feet, equivalent to a pressure of 173.6 pounds per square inch. The water is collected in a sump on the 2,300 level. The pumps are just above the sump (see figs. 4 and 5). The water is pumped up the winze from the 2,300 level to the 2,150 level, a vertical height of 250 feet. The pipe runs horizontally for about 54 feet on the 2,150 level, then it rises 150 feet vertically through an old stope to the 2,000 level. The water runs in a flume on the 2,000 level for a distance of 1,400 feet, then in the open crosscut for 500 feet. It then drops about 40 feet down a raise to a crosscut on the 2,100 level of the Portland No. 2 mine. It runs along the crosscut in a flume for 1,850 feet and enters the Roosevelt drainage tunnel.

The mine works two shifts - the day shift, from 7:30 a.m. to 4:00 p.m., and the night shift, from 6:00 p.m. to 2:30 a.m. Pumping is continuous, however, and requires that pumpmen and hoistmen work on a three-shift basis. Pumpmen are paid $138 per month. A mechanic is available for repair work on the pumps when needed.

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Electric power is purchased from the Southern Colorado Power Co. at Canon City. It is delivered to the substation at 6,600 volts and is there stepped down to 2,300 volts for the pump motors. The power cable is carried down the manway compartment of the main shaft. It is size 0, packed in jute and rubber, and lead-covered.

The cost of power for July 1936, representative of average power consumption, was made up as follows:

282,000 kw.-hr. @ $0.007	$1,974.00
Connected load on pumps, 550 hp. @ $1.00 .	550.00
Total power bill for July 1936	2,524.00

Pumping costs at the Ajax mine are shown in the following table:

	July 1936	7-month period, Jan. 1 to July 31, 1936
Labor	$ 538.75	$ 5,165.69
Compensation insurance	35.29	285.88
Supplies	90.14	1/ 809.98
Air	- - -	2/ 310.75
Power	2,524.00	12,267.60
Goulds pumps	3/ 396.20	4/ 1,639.53
230 feet of 12-inch pipe	- - -	5/ 684.00
	3,584.38	21,163.43

1/ Includes cost of concrete base.
2/ Air for sinker pump used to clean the winze on the 2,300 level; also for an air lift that is used to remove from the sumps the fine rock particles brought from fault zones.
3/ Cost of an assembly (an assembly lasts 4 or 5 months).
4/ Cost of the two Goulds pumps, including assembly.
5/ Balance of pump column is used 16-inch pipe borrowed from the Cresson mine.

Assuming an average pumping rate of 3,000 gallons per minute during July 1936, the pumping cost would be $0.027 per thousand gallons.

Cresson Consolidated Gold Mining and Milling Co.

The Cresson mine is a little over a mile north of Victor. (See fig. 1.) The altitude of the shaft collar is 10,030 feet above sea level. In September 1936 the mine was working three shifts a day. Drilling was done on the day shift, hoisting on the day and afternoon shifts, and on the night shift timber and steel were taken down and repairs made to the main shaft.

The mine was producing about 350 tons of ore a day, valued at about $10 per ton. Production was from above the 1,700 level, a little more than half of it being mined by the company and the rest by lessees. All ore mined was shipped to the Golden Cycle mill at Colorado City.

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Many interesting pumping problems have been encountered and solved at the Cresson mine. In December 1926, development work opened so much water-bearing ground that it became necessary to pump 5,800 gallons of water per minute. On April 29, 1929, with the mine making 3,300 gallons per minute, the pumps were pulled. The mine filled to within 17 feet of the level of the Roosevelt drainage tunnel, which at the Cresson mine is at an elevation of about 8,110 feet and corresponds to the 1,700 level of the mine. Connection to the tunnel was made in 1918[10/] by driving a lateral from the drainage tunnel to intersect a crosscut on the 1,700 level of the mine. On the 1,300, 1,900, and 2,000 levels of the mine, on both sides of the shaft and about 50 feet from it, are heavily reinforced steel water doors 3 feet wide and 5 feet 8 inches high. The general design is somewhat similar to that of the Ajax water doors. (See fig. 6.)

Pumping operations prior to flooding the lower levels have been described by Guy Rorabaugh[11/], master mechanic at the Cresson mine, to whom the writer is indebted for the information pertaining to the air-lift installation.

The objective of present (September 1936) dewatering operations is to drain the mine to the 1,800 level. Air lift was selected for the work because the former column pipes were in place and open at the bottom, space for pumping equipment in the shaft was limited to the manway, ample air-compressing machinery was already installed, and only incidental additional labor would be required.

The compressors are run by the fireman who tends the boilers for the steam hoist; he is paid $4.50 per day. There are three electrically driven compressors at the mine; they have the following specifications:

One 2,200-cubic foot compressor direct-connected to a 305-horsepower, 440-volt, 30-cycle, synchronous motor running at 200 r.p.m.

One 1,800-cubic foot compressor, belt-driven by a 250-horsepower, 440-volt, 30-cycle, induction motor at 165 r.p.m. This compressor is run only on day shift.

One 800-cubic foot compressor, belt-driven by a 100-horsepower, 440-volt, 30-cycle, induction motor at 165 r.p.m.

The air is delivered at a pressure of 100 pounds per square inch to two receivers, one 3 by 10 feet and the other 4 by 10 feet. It enters the mine through a 6-inch main air line.

In September 1936 about 35 drills were running in the mine. Four air-lift installations were in simultaneous operation in the main shaft. They

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10/ Bebee, A. H., and Johnson, C. H., Mining Methods and Costs at the Cresson Mine, Cripple Creek, Colo.: Information Circ. 6806, Bureau of Mines, November 1934, 14 pp.

11/ Rorabaugh, Guy, Drainage and Pumping at the Cresson mine: The Mining Congress Journal, vol. 15, no. 3, March 1929.

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consisted of one 6-inch discharge pipe with a 1-inch air line, one 8-inch discharge pipe with a 1-1/2-inch air line, and two 9-inch discharge pipes with 1-1/2-inch air lines. The lift (pumping head) was about 127 feet. Both 9-inch lines and the 6-inch line are old pump columns; they extend to the 2,000 level. The 8-inch line extends 300 feet down the shaft from the 1,700 level (fig. 7); top and bottom connections are shown in figure 8. Another type of top connection that has been used at the Cresson mine is shown in figure 9. Many types of foot-pieces have been used; figure 10 shows the foot-piece on the 6-inch line.

The discharge pipes of all the lifts make a right-angle turn on the 1,700 level and extend practically horizontally for about 800 feet, except that the discharge from the 8-inch lift and that from one of the 9-inch lifts are combined near the shaft in a 12-inch discharge pipe. Beyond the end of the discharge pipes the grade of the crosscut accomodating them reverses and slopes toward the Roosevelt drainage tunnel, that part of the connection having been driven from the tunnel. The water is released from the pipes behind a dam, over which it flows into the crosscut and joins the quiet water above a weir. The weir is of the contracted type; the width of the opening is 46 inches. Water measurements are made at the weir continuously on a revolving chart; the set-up is shown in figure 11. Every 24 hours the chart is removed by the master mechanic. The height of the water surface above the weir is averaged for a 24-hour period, the elevation of the crest of the weir being zero on the chart. The average shown on the chart is doubled, since the recording pen is on a vertical lever arm only half as long as the horizontal arm. (See fig. 11.) The height of the water surface is taken from the quiet water about 6 feet back from the weir. The quantity of water flowing over the weir in a 24-hour period, that is, the water discharged by the air lifts during that period (8 a.m. to 8 a.m.), is found from the formula[12]

$$Q = 0.4\ (lh^{3/2})$$

where Q = quantity of water in cubic feet per minute,
l = length of top edge of weir in inches (46 in this case),
h = height of water surface above crest of weir in inches.

The quantity found may be converted into gallons per minute by multiplying the number of cubic feet per minute by 7.48. On August 10, 1936, the chart showed an average head of 6.35 inches; the discharge was recorded as 2,220 gallons per minute.

The average number of gallons per minute pumped each day, and the water level in the main shaft and in the 1704 stope, are plotted on a graphic log kept in the engineering office. A reproduction of the log (figure 12.) shows the lowering of the water table with continued pumping, rapid at the beginning, then more gradual, then rapid again when the 8-inch lift was added.

12/ Not strictly applicable to a contracted weir; probably used for convenience of calculation.

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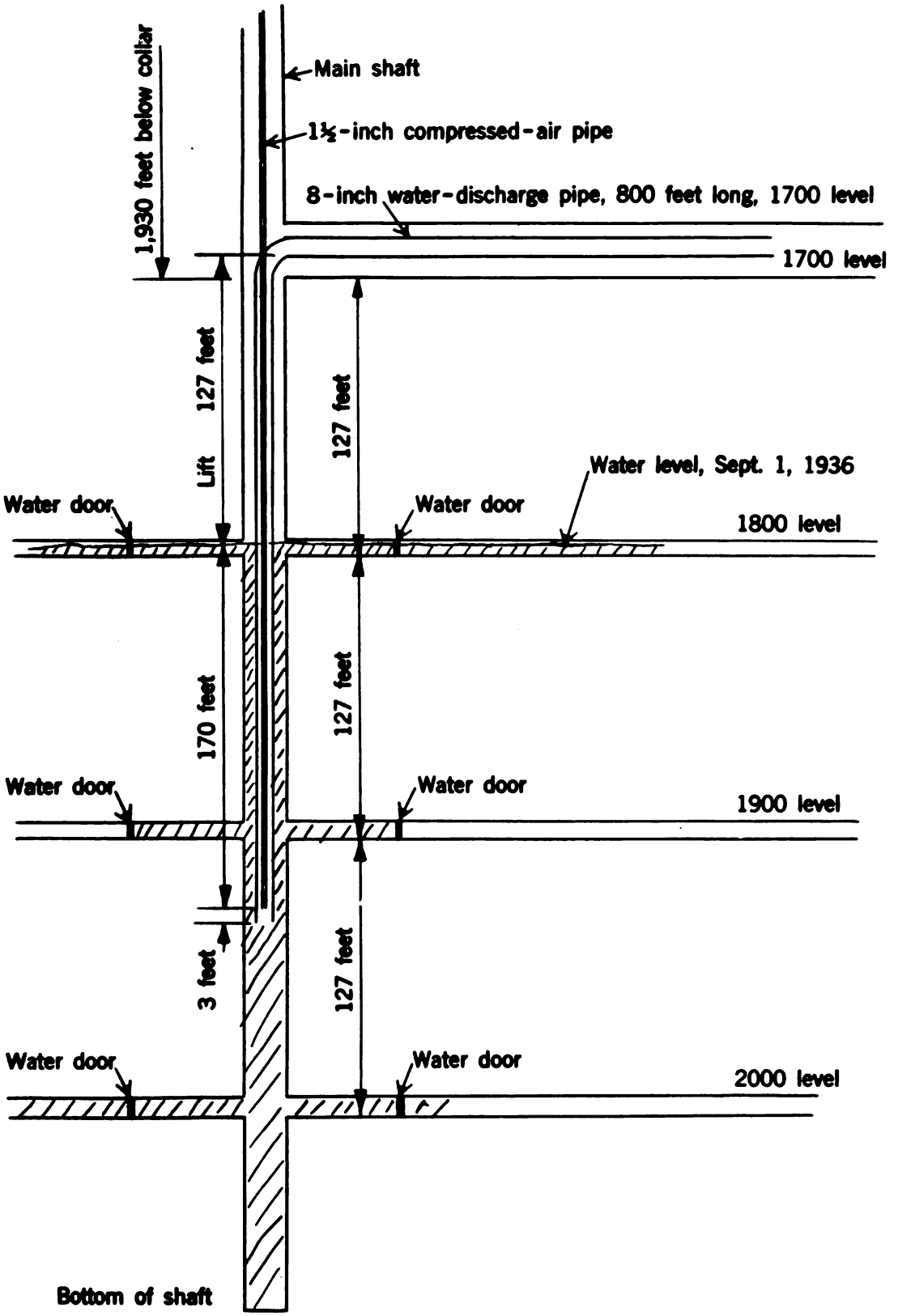

Figure 7.— Vertical section showing 8-inch air lift installation, Cresson mine. (Not to scale.)

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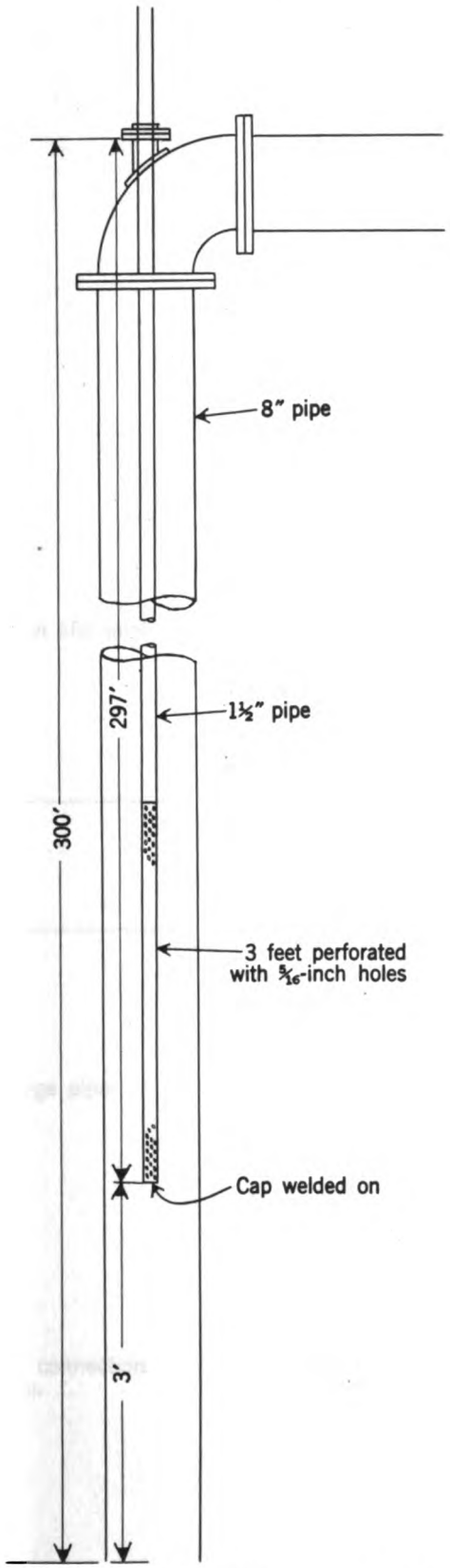

Figure 8.—Top and bottom connections, air lift, Cresson mine.

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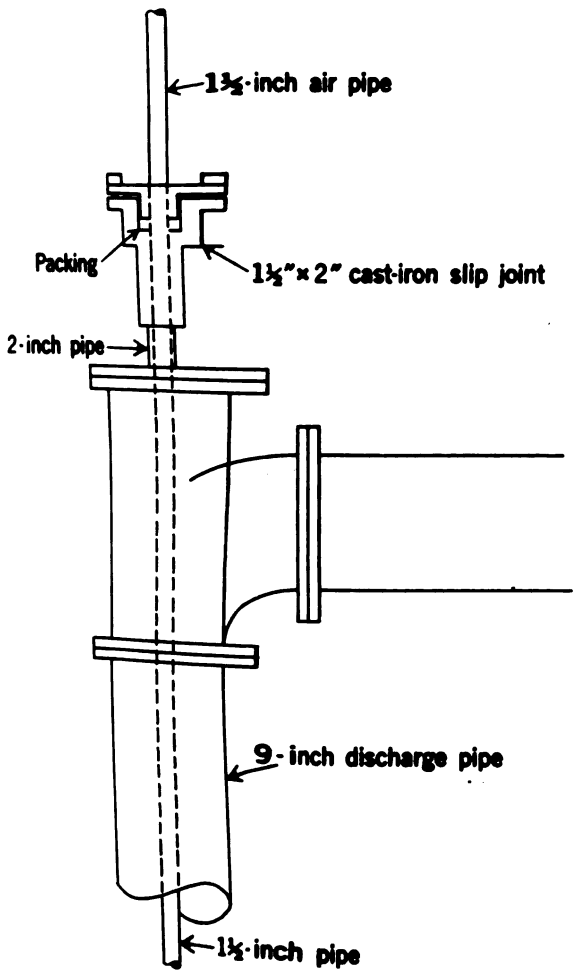

Figure 9.—Optional type of top connection used at Cresson mine.

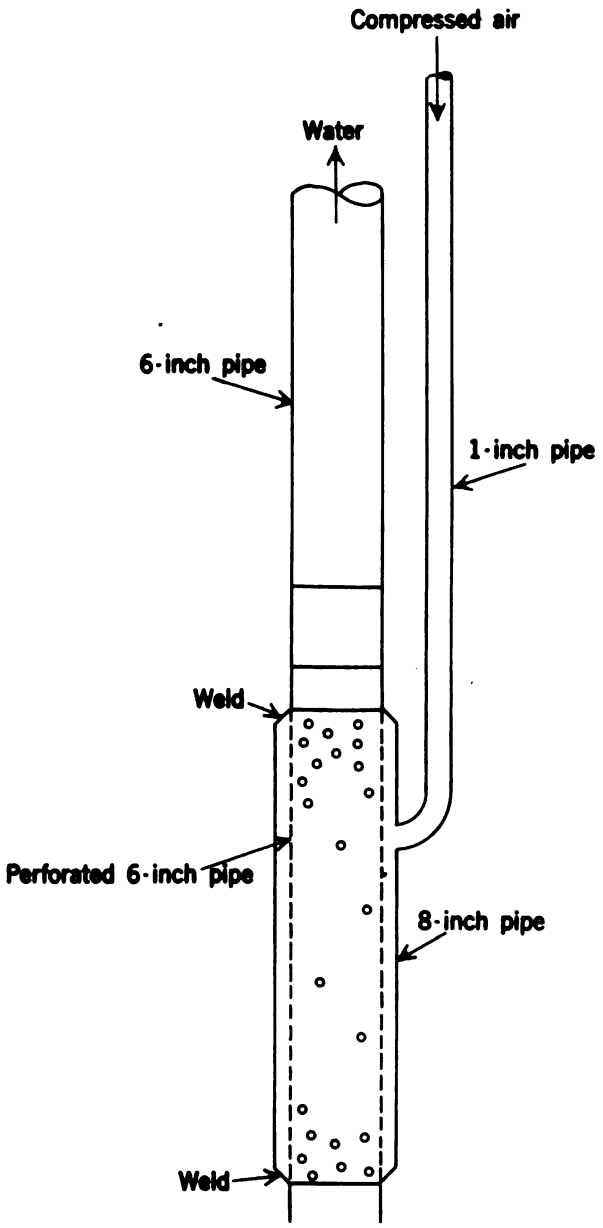

Figure 10.—Foot piece of 6-inch air lift at Cresson mine (in sump on 2000 level).

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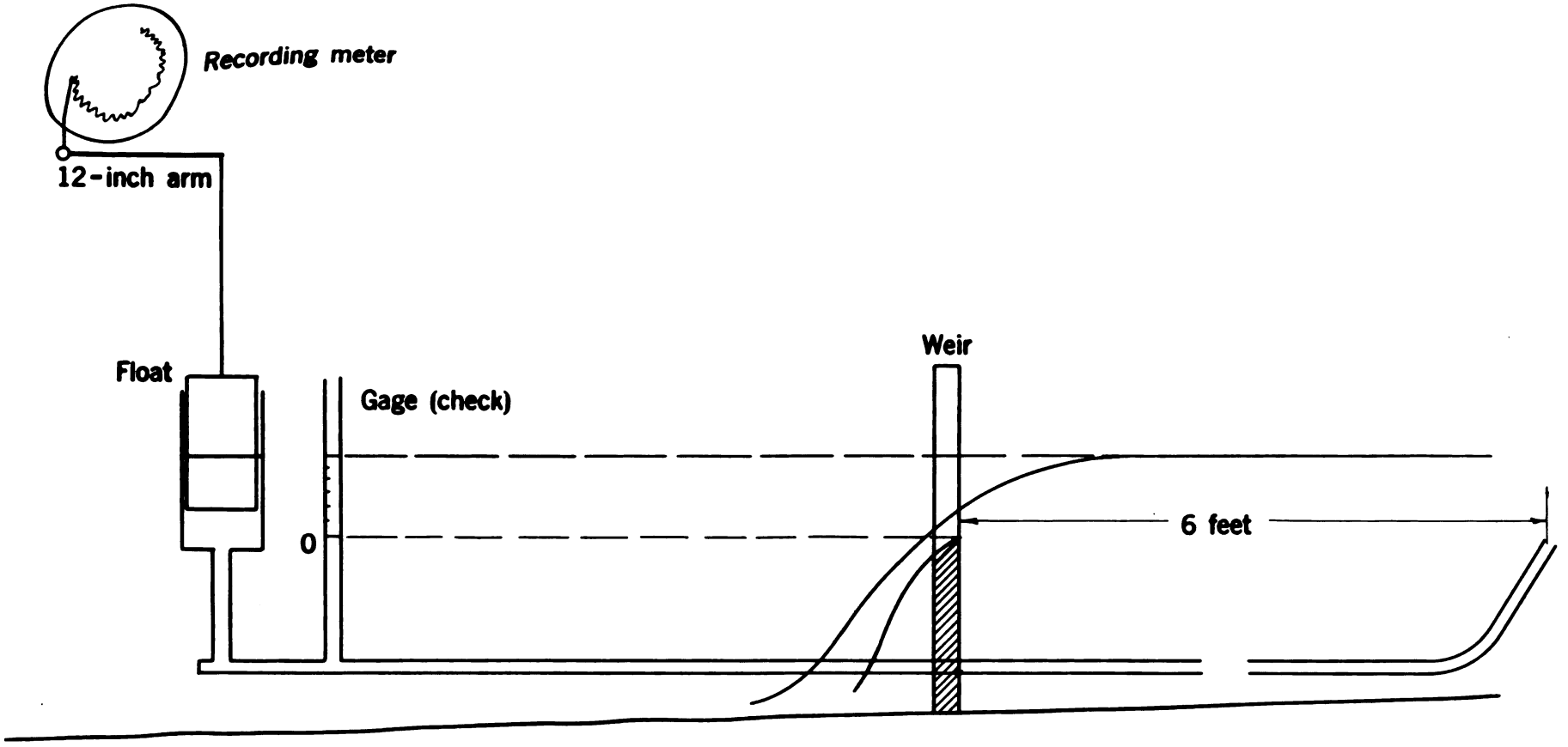

Figure 11.—Weir at Cresson mine.

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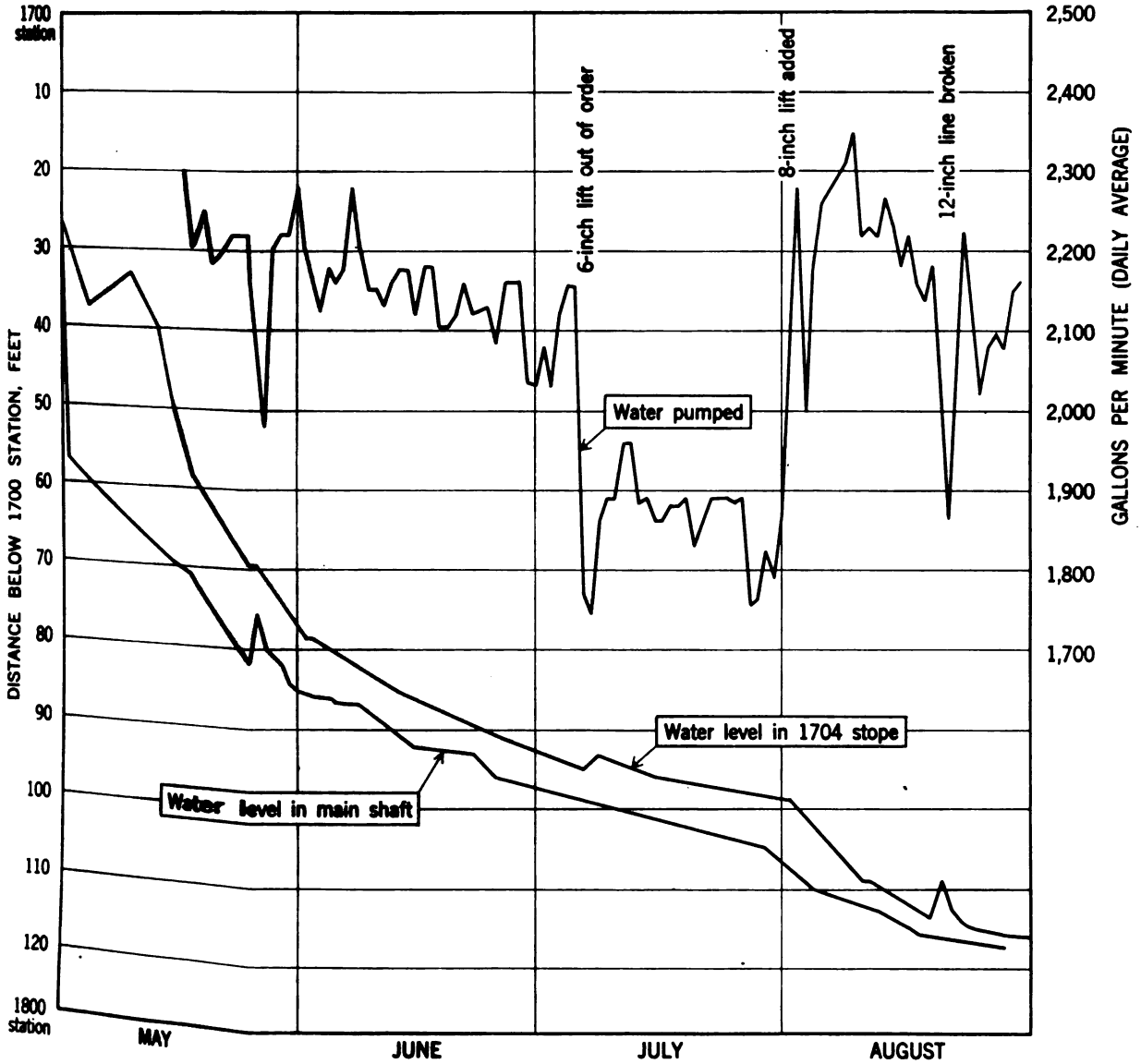

Figure 12.—Graphic log of unwatering operations, Cresson mine.

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A continuous record of the air pressure is kept on a recording pressure gage. Drops in the quantity of water discharged by the air lifts are usually accompanied (allowing for a little lag) by drops in the air pressure. A drop in the water pumped without a corresponding drop in the air pressure is an indication that the air lifts are not functioning properly.

The master mechanic keeps a daily log of the performance of the air lifts, including memoranda of alterations, repairs, etc., as shown in the following tabulation:

Log of air-lift pumping

Date	Gallons per minute	Remarks
1936		
May 15	2,300	Air pipe for lift No. 1, 6-inch, 256 feet long. Air pipe for lift No. 2, 9-inch, 240 feet long. Air pipe for lift No. 3, 9-inch, 258 feet long.
May 21	2,165	Changed air pipes to 270 feet. Total for May 15-31 = 54,188,800 gallons. Average gallons per minute = 2,215. Overall efficiency = 17.3 percent. Water in main shaft at 85 feet below 1,700 level. Cost of power per 1,000 gallons = $0.01178.
June	--	Total for June = 92,400,000 gallons. Average gallons per minute = 2,138. Overall efficiency = 20.8 percent. Cost of power per 1,000 gallons = $0.0113.
July 5	2,160	
July 6	1,775	6-inch lift out of order. Repaired by raising air pipe. Total for July = 84,981,000 gallons. Average gallons per minute = 1,900. Cost of power per 1,000 gallons = $0.0135.
Aug. 2	2,280	
Aug. 3	2,000	
Aug. 4	2,185	Added 25 feet to air lines on the two 9-inch lifts.
Aug.20	2,022	
Aug.21	1,865	12-inch discharge line broke in crosscut (cost about $30.00 to repair).
Aug.23	2,100	
		Total for August = 96,196,000 gallons. Average gallons per minute = 2,160. Overall efficiency = 19.8 percent.

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The compressed air used for the air lifts is provided by the electrically driven compressors already described. Inasmuch as the same compressors furnish air for drilling, the amount of power properly chargeable to pumping is not known definitely.

Power for drilling costs $0.01 per kw.-hr., whereas power for pumping costs $0.007 per kw.-hr.; therefore, it was necessary to divide the power between "operating" and "pumping" on a definite basis. The following procedure was used:

Power used in-	Kw.-hr.
January 1936	133,050
February	143,550
March	147,150
April	138,900

Monthly average = 140,662 kw.-hr. used for operating only; the air-lift pumping did not begin until May 15, 1936. For subsequent months, the power charged to pumping is the total metered kw.-hr. less 140,662. But the mine must pay for 160,000 kw.-hr. at $0.01. The difference (160,000 - 140,662), 19,338 kw.-hr., is therefore charged to pumping at $0.01 per kw.-hr. The rest of the power used for pumping is paid for at $0.007 per kw.-hr. During the month of July 1936:

Power chargeable to pumping	155,288 kw.-hr.	
Paid for at $0.01 (160,000 - 140,662)	$ 19,338	$193.38
Paid for at $0.007	135,950	951.65
Cost of power for pumping, July 1936		$1,145.03
Total gallons of water pumped during July	84,981,000.	
Cost of power per 1,000 gallons pumped in July		$0.0135

Vindicator Mine of the United Gold Mines Co.

The Vindicator mine is in the town of Independence, 2 miles north of Victor. The collar of the main shaft is 10,209.4 feet above sea level. The pump station is on the 2,100 level and the bottom of the shaft is about 10 feet below that level. The pumps were drowned in 1921. The water rose to the 2,000 level and remained there for 15 years. In January 1936 the mine was unwatered. It took 31 days to lower the water to the 2,100 level, which is 125 feet below the 2,000 level. Air lift was used for most of the distance, a 4-inch discharge pipe with a 1/2-inch air line welded to the outside of it being used; sinking pumps finished the work. Thereafter, pumping has been continued from the 2,100 station so that four leases on that level might be operated.

The water is pumped from the sump on the 2,100 level up to the 2,000 level, a pumping head of 125 feet. The water runs "open" on the 2,000 level for 1,800 feet and then drops down a 65-foot raise to the Roosevelt drainage tunnel. Surface water is intercepted on the 400 level and on the 1,000 level.

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From small sumps on those levels the water is conducted through a 3-inch pipe to the 2,000 level, where it runs into the Roosevelt drainage tunnel. During the spring and in July and August the small sumps on the 400 and 1,000 levels sometimes overflow.

The quantity of water pumped from the 2,100 level is not affected by seasons; it depends upon the water channels cut by the mine workings. Apparently the water channels in the Vindicator ground are distinct from those at the Ajax or Cresson mines; pumping in the latter two mines does not affect the water level at the Vindicator. The Vindicator mine and the neighboring Golden Cycle mine cut the same water channels. The water in the Vindicator mine is clear and only very slightly acid. It was drunk, without harmful effects, by a mule used in the mine.

In September 1936 pumping equipment at the Vindicator mine consisted of the following:

Capacity, gal. per min.	Make	Type	Hp. of motor	Suction pipe, inches	Discharge pipe, inches
500	Byron-Jackson	Single-stage centrifugal	35	5	4
750	Lecourtenay	3-stage centrifugal	100	6	5
1,500	Manistee	Single-stage centrifugal	100	6	5
2,750					

These pumps were used because they were available and could handle the water. They are set on a platform 3 feet above the floor of the 2,100 level and are driven at 1,700 r.p.m. by individual direct-connected, 2,300-volt, 3-phase, 30-cycle motors. In September 1936 about 1,400 gallons per minute were being pumped from the 2,100 level. To handle that amount, the Manistee pump, running alone, was used alternately with the two other pumps working together.

The sump on the 2,100 level is the extension of the shaft below that level; it is 5 by 16 feet in section and 10 feet deep. Every two months the sump is cleaned with a sinking pump after first closing the water door. The door on the 2,100 level is about 40 feet from the shaft and is constructed of a 1-inch steel plate, 4-1/2 by 5-1/2 feet in size, heavily reinforced both ways with 80-pound rails. The concrete foundation is recessed for packing, against which the door closes.

The mine works only one shift; the pumps, three. The State law requires a hoist man to be on the surface while the pump man is in the mine. The hoist men on the 4 o'clock and 12 o'clock shifts have no other duties than to serve the pump men. The daily labor cost of pumping is therefore as follows:

Three pump men at $4.90	$14.70
Two hoist men at 5.45	10.90
	25.60

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Electric power for pumping is purchased from the Southern Colorado Power Co. It is stepped down from 22,000 volts to 2,300 volts on the surface. The cost of power is $0.01 per kw.-hr. plus the horsepower demand. Power is metered on the primary side; distribution of power costs was not available. Lightning causes the only interruptions in the power service; during July and August 1936 the power failed 15 or 20 times due to lightning.

SUMMARY AND CONCLUSIONS

In the summer of 1936, the three mines herein described were pumping water under the following conditions:

Mine	Type of pump	Pumping head, in feet	Gallons pumped per minute	Pumping cost per 1,000 gallons
Ajax	Centrifugal	400	3,000	1/ $0.027
Cresson	Air lift	127	2,100	2/ .0135
Vindicator	Centrifugal	125	1,400	3/ .0127

1/ For July 1936; see p. 8 for items included in pumping cost.
2/ For July 1936; cost of power only (see p. 12).
3/ Cost of labor only (see above).

Deep development is the outstanding feature of present (1936) mining activity in the Cripple Creek district. To the mines whose workings extend below the level of the Roosevelt drainage tunnel, deeper development introduces pumping costs that increase with the depth of development. Pumping costs are high on account of the large quantities of water to be raised; power rates are relatively low. The discovery of ore bodies several hundred feet below the present water level that yield a substantial profit in spite of pumping costs should continue to stimulate deep development in the district.

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